Smooth Particle Hydrodynamics for Surf Zone Waves

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LONG-TERM GOALS

Smoothed Particle Hydrodynamics (SPH) is a meshless numerical method that is being developed for the study of nearshore waves and other Navy needs. The Lagrangian nature of SPH allows the modeling of wave breaking, surf zones, ship waves, and wave-structure interaction, where the free surface becomes convoluted or splash occurs.

OBJECTIVES

The objectives of this project are to improve the SPH model for use in unraveling the physics of breaking waves, including the description of the wave-induced turbulence and sediment transport within the surf zone. In addition, the interaction of waves with structures is being investigated.

APPROACH

The approach is based on improving various aspects of the SPH code, including the development of a graphics processing unit (GPU) version of the code (GPU-SPHysics); applying the code to more validation tests; and to examine in some detail new aspects of the model by applying it to different situations. The development of a hydrid model, that is, coupling the SPH particle model to a conventional finite difference model (a Boussinesq model, FUNWAVE) has been achieved.

WORK COMPLETED

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- A hybrid SPHysics/Boussinesq code has been developed
- GPU-SPHysics, a C++ GPU-accelerated code, was developed with INGV, Italy
- 14 calibration and test problems have been developed, including breaking waves on beaches.

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RESULTS

SPH models are computationally intensive—requiring numerous particles (nodal points) for resolution and very small time steps. Although with parallel computing larger and larger areas can be modeled with SPH, it is more reasonable to develop hybrid models, such that more efficient computational models are used in most of the domain and SPH is used where its capabilities are useful—in wave breaking, for example. To this end, a coupled model, comprised of a Boussinesq model, which uses depth-integrated equations, and SPHysics, for the nearshore, has been developed. The University of Delaware model, FUNWAVE (Wei & Kirby, 1995), was used to build the hybrid model. In Figure 1, the propagation of a solitary wave in a tank is modeled: a solitary wave propagate from left to right, into a vertical reflective wall, and the wave reflects back to sea. The hybrid model has FUNWAVE computing the solitary wave in the left 2/3 of the figure, both models computing the wave in the shaded overlap region, and SPHysics computes alone in the right end of the tank. Tests have been carried out to compare the hybrid model to a FUNWAVE-only result. Agreement between the full FUNWAVE model and the hybrid FUNWAVE-SPHysics model is reasonably good. A 2008 JHU Ph.D. disseration by Narayanaswamy decribes this model.

A major effort this year has been the development of *GPU-SPHysics* and its application to water waves and free surface flow problems. This code, written in C++ and utilizing massively parallel Nvidia graphics cards to do the numerical work, runs orders of magnitude faster than the serial code SPHysics (www.sphysics.org), which was inspiration for *GPU-SPHysics*. We are using 3 Nvidia Tesla GPU cards (each with 240 streaming processors) to run the *GPU-SPHysics* code. Currently only one card is used per problem; however, development efforts are underway to develop a multi-GPU *GPU--SPHysics* code. (This will be augmented by the acquisition of an NSF-funded 100 Tesla card cluster computer—to be constructed in 2010.)

The *GPU-SPHysics* code, initiated by Dr. Alexis Hérault at the Istituto Nazionale di Geofisica e Vulcanologia in Sicily, has been applied to water wave problems (Hérault *et al.*, 2009a, Hérault *et al.*, 2009b), as well as lava flows on Mount Etna. We are currently able to run models with about 4 million particles.

This flexible code can now be run with five different smoothing kernels, fixed or variable time steps, Shepard or MLS filtering, Chen-Beraun kernel correction (Chen & Beraun, 2000), two different boundary conditions (Lennard-Jones repulsive forces, or a Monaghan & Kajtar (2009) repulsive force). Further, there are 3D and 2D versions of the code. The coding is object-oriented, and numerous objects have been developed that can easily be introduced into problems, such as rectangles, cubes, spheres, and cylinders. Already, test cases have been developed for wave interaction with cylinders and rectilinear objects (from the Cube object).

Figure 2 shows a GPU-SPHYsics result for waves generated by a flap wave paddle in a wave tank with a compound flat-sloping bottom, resulting in a beach. Ten surface-piercing periodically spaced piling (in three rows) are placed in the breaking wave zone and are periodically overtopped by the breaking waves. The breaking wave flow between the piling and on the beach face is shown.

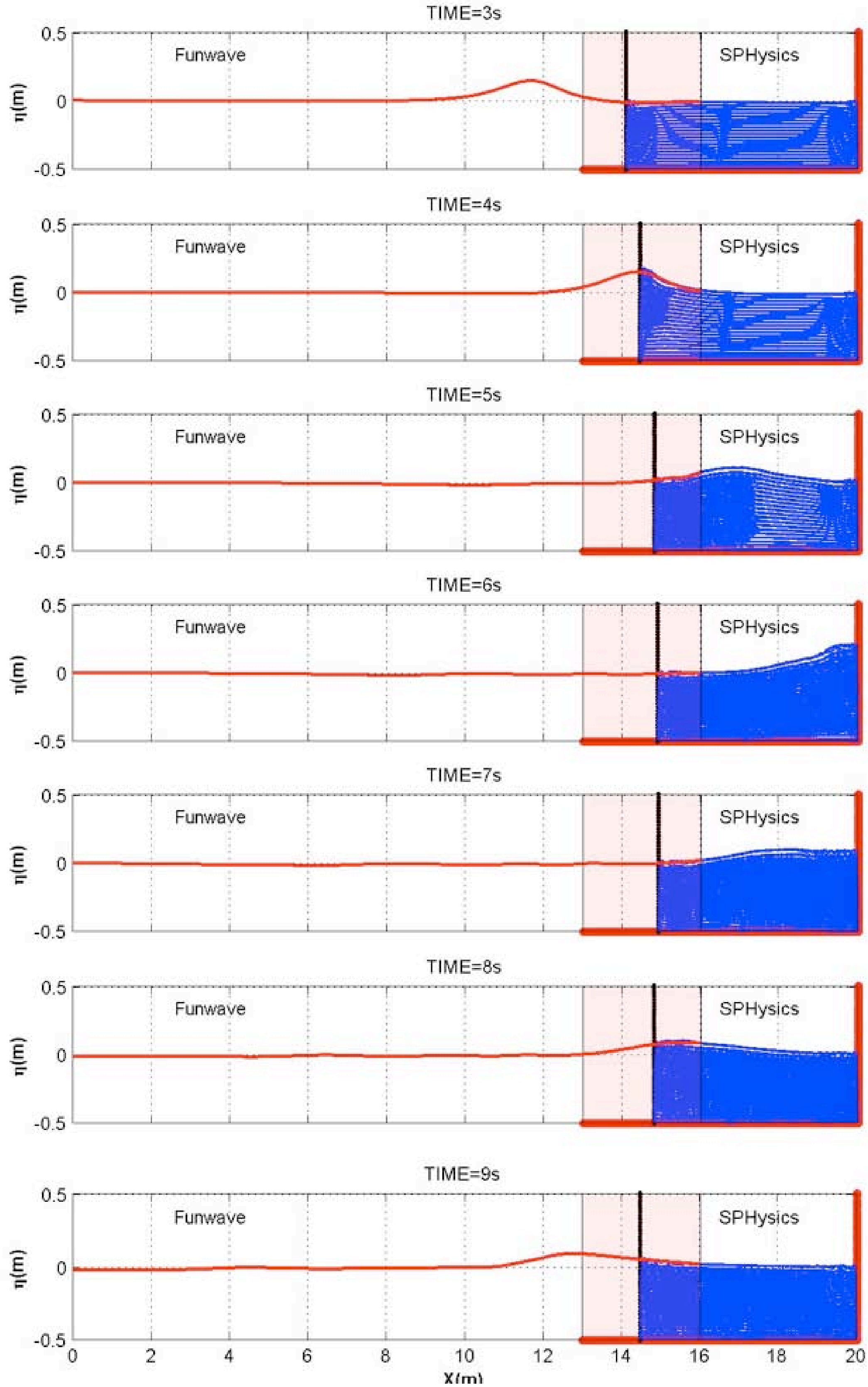

Figure 1. Incident and then reflected solitary wave computed by a hybrid FUNWAVE and SPHysics model. Shaded region is the overlap region. Reflective vertical wall at right.

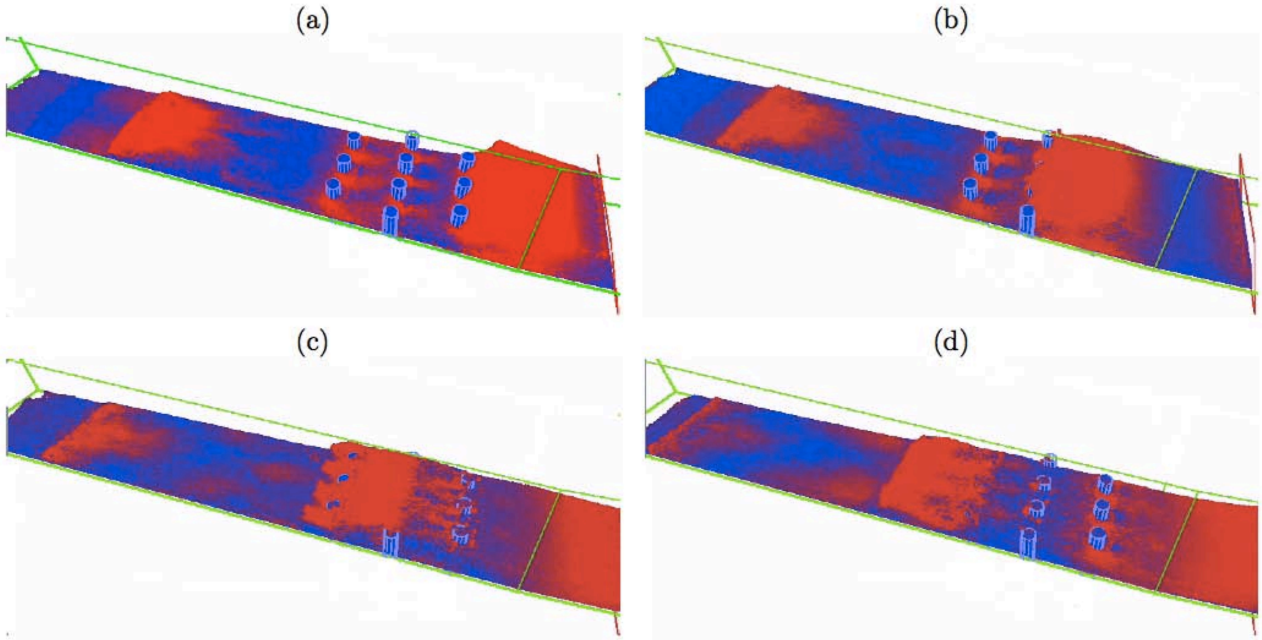

Figure 2. Breaking waves in surf zone impinging from the right and breaking on three rows of surface-piercing piling. The red color denotes high velocity regions. Time increases from 2a to 2d. Note the turbulent flow between piles and in the surf zone in general.

Test cases that have been developed within GPU-SPHysics include: Barge (to examine the bow and stern waves associated with a moving barge), Breach (instantaneous wall section failure of a floodwall), DamBreak3D, DamBreak2D, DamBreakGate (these DamBreak cases are used to validate against laboratory data of flow generated by the opening of a dam, e.g. Crespo et al.,), Jet (a water jet impinging on still water), OpenCoast (a wide section of a planar beach with incident waves), Overtopping (waves overtopping a wall), PaddleTest3D (wave tank with flap wavemaker), PowerLaw (gravity driven flow, with objects in the flow. For example, pylons in a river), SlidingBlock (wave or tsunami generation by a block sliding along a plane into still water), WallFail (slowly falling floodwall section and subsequent flooding of buildings), WaveBench (tsunami impact on sloping shoreline with focusing and breaking) and WaveTank (wave tank with structures in the tank—used to generate Figure 2). Due to the object oriented nature of the code, adding additional objects to problems is just several lines of code; for example, adding another piling to Figure 2 requires only three lines of code.

One of the interesting problems of water waves is that breaking plunging wave jets bounce off the toe of the wave and rebound to break again. Peregrine (1983) examined this phenomenon and developed a good explanation for very shallow water—the plunging jet works like a snow plow, interacting with the bottom to throw up the water in front of the wave. In deeper depths, this is not likely to be true.

In Figures 3, four instances of a translating high-speed planar jet impinging onto still water is shown using 2D GPU-SPHysics. These results agree well with laboratory work by J. H. Duncan and colleagues at the University of Maryland, who examined translating planar jets as a model of plunging breaker jets. For the translation speeds that they tested, no splash-up of an impinging jet was observed—all the laboratory jets penetrated the water. However, with GPU-SPHysics, we can extend

the range of the laboratory experiments, and we observe that when the speed of translation of the jet is equal to the speed of fluid comprising the jet, then the jet bounces. This is shown in Figure 4. Bouncing jets appears to be restricted to planar jets (2-D jets), as cylindrical jets, based on modeling to date, do not bounce, but splash in all directions.

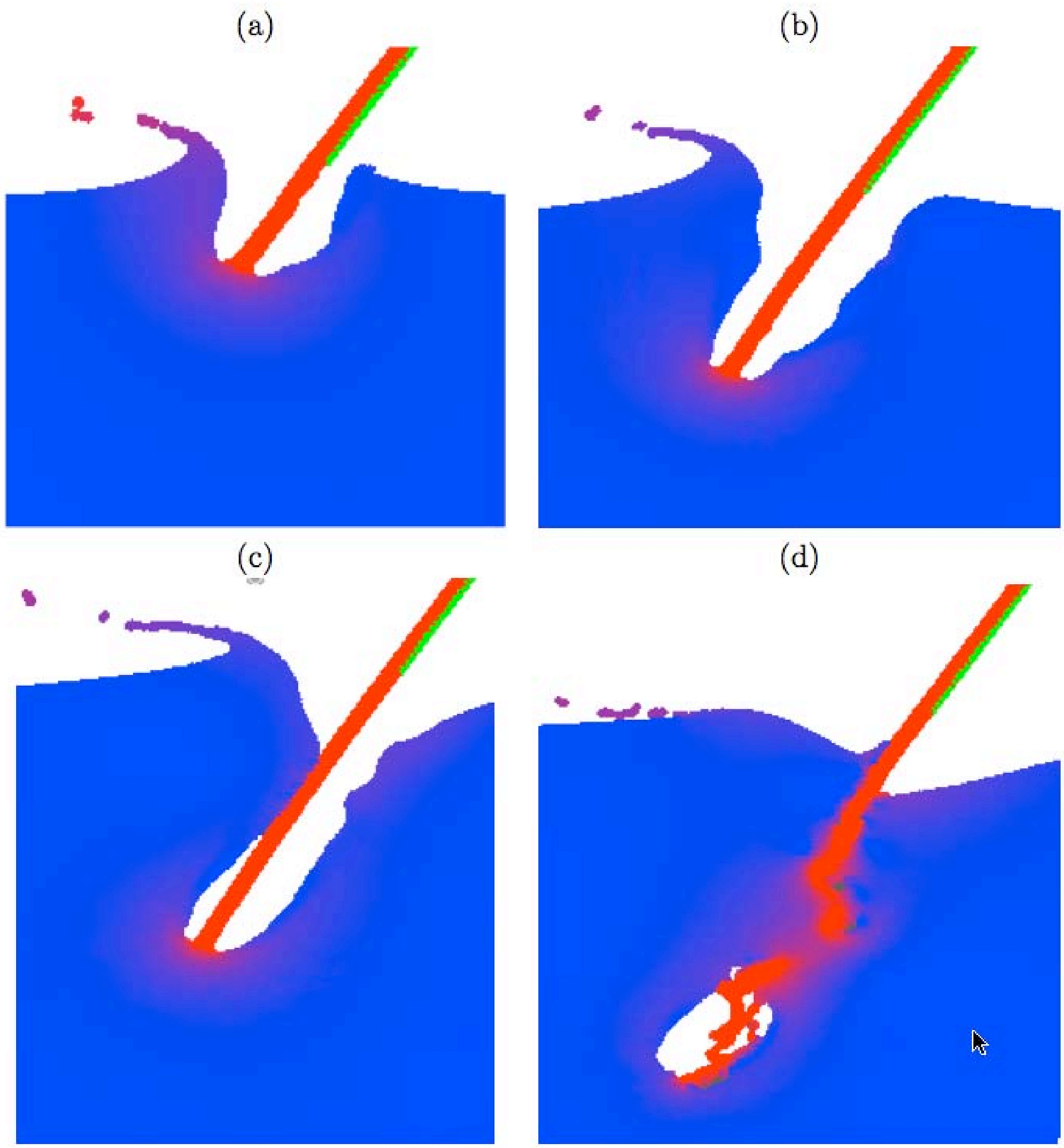

Figure 3 A slowly moving impinging jet shown at four different times. In 3a and 3b, the impact cavity is created by the impact of the jet. In 3c, the moving jet and the collapsing cavity collide. In 3d, the cavity has fully collapsed onto the jet.

International Collaborations: Our international collaborations with the Universities of Vigo (Gómez-Gesteira and Crespo), Rome (Panizzo, Capone), and Manchester (Rogers) led to the release of an open source code, SPHysics on August 1, 2007. Version 1.4 was released on February, 2009. The URL is http://www.sphysics.org. The code has been downloaded over 2,000 times. A new

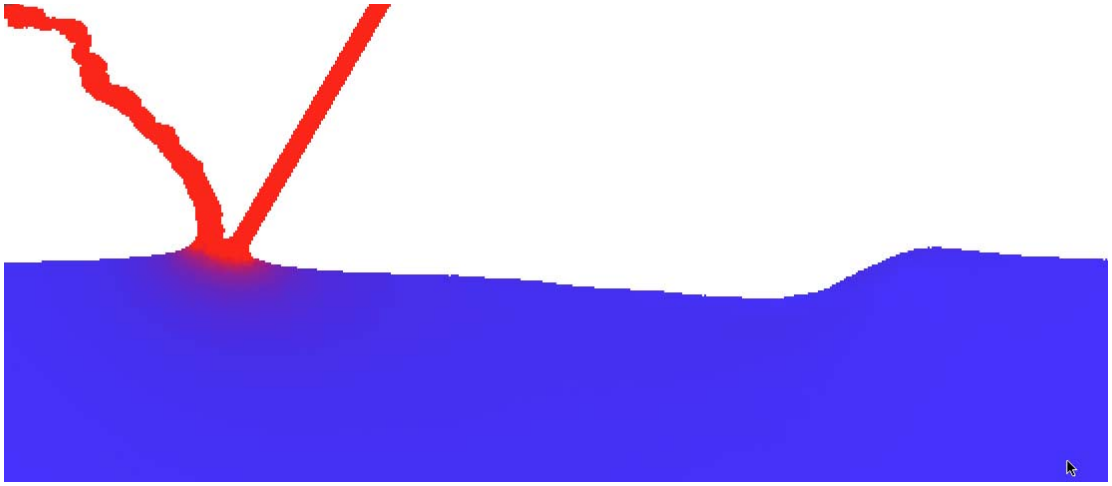

Figure 4. Translating planar jet, moving right to left, impinging onto still water. Velocity of water in incident jet is 2.2 m/s. Translation speed of the jet is 2.5 m/s. The jet bounces forward. The surface depression at the right is located at the initial impact point of the jet.

collaboration over the past year has been established with the Istituto Nazionale di Geofisica e Vulcanologia, sezione di Catania, for the development of GPU-SPHysics. Drs. Hérault and Bilotta were in residence at JHU during January of 2009. Dr. Joe Monaghan, a co-inventer of SPH visited us in August for 5 days, and Dr. Benedict Rogers, one of the SPHysics developers, was also here for 12 days in August working on GPU-SPHysics implementation of SPS viscosity and the Monaghan-Kajtar boundary conditions.

IMPACT/APPLICATIONS

Smoothed Particle Hydrodynamics is proving to be a competent modeling scheme for free surface flows in two and three dimensions. Coupled with another wider-area wave model, such as Boussinesq, a hybrid SPH model provides a large, highly resolved, look at an entire surf zone.

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